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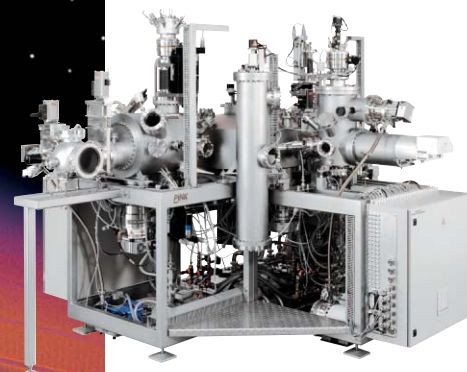
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# Vacuum challenges and solutions

Reliability and innovation are touchstones for the vacuum industry in the 21st century. Reliability is needed to get the most out of expensive manufacturing equipment, while innovation is essential to cope with the increasingly complex demands that are being placed on the suppliers of vacuum equipment by a range of customers. This special *Physics World* supplement starts with a general introduction to vacuum science and technology by Ugo Valbusa, the president of the International Union for Vacuum Science, Technique and Applications (p5). This is complemented by a summary of the broad field of vacuum coating, including the crucial process that goes by the name of “sputtering” (p11), advice about how a Master’s degree can improve your career prospects in the vacuum industry (p9) and a trio of case-studies from different vacuum companies (pp7, 15 and 17). This is the fourth year in a row that *Physics World* has published a vacuum supplement. We hope you enjoy it as much as you did the previous three.



**Modular system for producing and analyzing thin films e.g. kuprat superconductors, layer manganates, heteroepitaxial hybrid structures and metallic layers.**

## Contents

### Vacuum around the world **5**

The International Union for Vacuum Science, Technique and Applications represents all sections of the vacuum community, as its president, Ugo Valbusa, explains

### Rising to the uniformity challenge **7**

Building a “showerhead” for a gas reactor presented several challenges, as Paul Brooker of Creative Group describes

### Mastering the vacuum **9**

An MSc in vacuum technology is a passport to a career in many different industries. Philip Parsons recounts how he landed a job at GV Instruments

### The secret world of vacuum coating **11**

What do drill bits, food packing and architectural glass have in common? They all rely on vacuum coatings, as David J Christie of Advanced Energy Industries reports

### Innovative approaches to pumping **15**

Architectural glass production places big demands on pumping systems. Willijan Vissers of Varian Incorporated describes what is involved.

### Model shows how to turn one pump into two **17**

How do you convert an ordinary turbo pump into a split-flow version? Andy Pearce of Oxford Vacuum Science explains all

### Diary **18**



**Patented vacuum/inert-gas inline soldering system VADU 300 for void free soldering of electronical components.**



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**Front cover:** Advanced gas delivery system developed by Creative Group for Thomas Swan Scientific Equipment.

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# Vacuum around the world

## The International Union for Vacuum Science, Technique and Applications represents all sections of the international vacuum community

Most research labs rely on vacuum conditions and equipment to some degree. Vacuum technology is used in high-energy physics experiments, space simulations, surface science and many other areas of research. The list of research equipment that relies on vacuum conditions is extensive: electron microscopes, analytical mass spectrometers, scanning tunnelling microscopes, ion implanters, molecular beam epitaxy equipment, particle storage rings, film evaporators and a host of analytical tools that are used to probe the properties of surfaces – from low-energy electron diffraction and Auger spectroscopy to field ion microscopy and X-ray photoelectron spectroscopy.

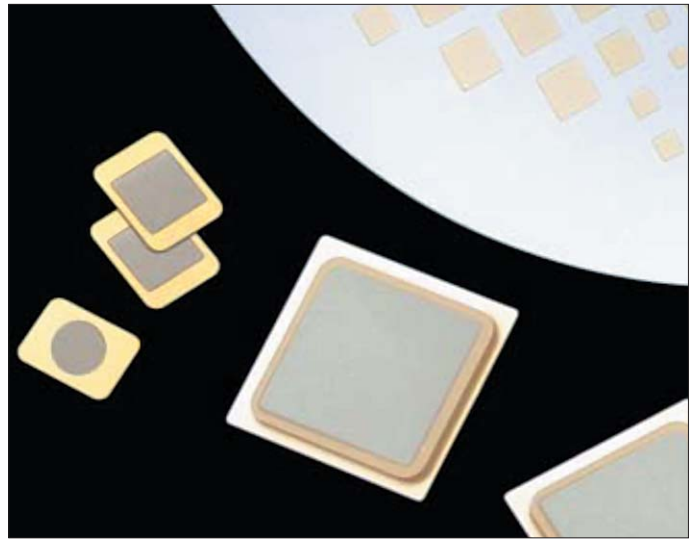
Vacuum technology is also used extensively in industry; for example, in the manufacture of integrated circuits and electrical components, vacuum packing and forming, thermal insulation, gas sampling, degassing of oils, distillation, and in metallurgical, pharmaceutical and chemical processes. The food industry, for instance, employs vacuum during freeze-drying – a process that enables most foods to be stored without refrigeration. The production of vacuum lamps, X-ray tubes, field-emission display devices and display technologies used for television screens requires a pressure of about  $10^{-6}$  mbar.

A plethora of products used in the world today are based on thin-film coatings technology. These products range from machine tools that have been coated to increase their lifetime, through decorative finishes on various materials (including metals, plastics and ceramics), to anti-reflection coatings on eyeglasses and camera lenses.

The traditional techniques used to reach vacuum conditions in standard vacuum equipment are now being implemented for nanotechnology applications too. SAES Getters, for example, is applying vacuum techniques that were originally developed for vacuum electron devices in the early days of electronics to microelectromechanical systems (MEMS) technology. To work properly, a MEMS device needs to be inside a hermetically sealed vacuum. The “getter” film can be activated during the bonding process and will continue to work as required during the lifetime of the device, thus ensuring long-term reliability and low cost.

Inertial sensors based on MEMS devices that work in a vacuum are an established industry, with performance:cost ratios improving each year. MEMS will soon make many non-MEMS components obsolete and should also open up new applications owing to their small size and weight, modest power consumption and cost. However, this will require co-operation between physicists, chemists, materials scientists, engineers and technologists who are active at every stage, from basic and applied research, through development to manufacturing.

The International Union for Vacuum Science, Technique and



**SAES-Getters has integrated the “getter” into MEMS devices that need a vacuum or a moisture-free, gas-filled environment.**

Applications (IUVSTA), which was founded in 1962, plays a key role in bringing together all of these different scientists, engineers and technologists to discuss issues of common interest and to promote the use and development of vacuum science and technology. IUVSTA also unites the vacuum communities of different countries. Indeed, 30 national vacuum societies, including 20 from Europe, are members of the union, which now represents almost 15 000 scientists and technologists worldwide.

IUVSTA promotes and coordinates international meetings and develops educational material for international use. It also has the following divisions: applied surface science; electronic materials and processing; nanometre structures; plasma science and techniques; surface engineering; surface science; thin film; and vacuum science and technology. A programme of workshops and schools provides a forum for discussion within these divisional areas. This programme has organized 42 workshops and seven schools since it was established in 1977.

One of the most important functions of IUVSTA is to organize the International Vacuum Congress, which takes place every three years. At the next congress, IVC-17, which will be held in Stockholm, Sweden, from 2 to 6 July 2007, IUVSTA will present two prestigious prizes that recognize and encourage outstanding internationally acclaimed research and achievements in technology and instrumentation. IUVSTA is also involved in organizing other conferences, such as the International Conference on Thin Films, the European Vacuum Conference, the Vacuum and Surface Sciences Conference of Asia and Australia, and the European Conference on Surface Science.

The European vacuum community is particularly active in IUVSTA, and a committee of European representatives has been established to provide a forum for discussion about coordinating activities at the European level.

**Ugo Valbusa is president of IUVSTA ([www.iuvsta.org](http://www.iuvsta.org)) and professor of physics at the University of Genova, Italy ([server1.fisica.unige.it/~valbusa/webpage/paginaweb.html](http://server1.fisica.unige.it/~valbusa/webpage/paginaweb.html))**

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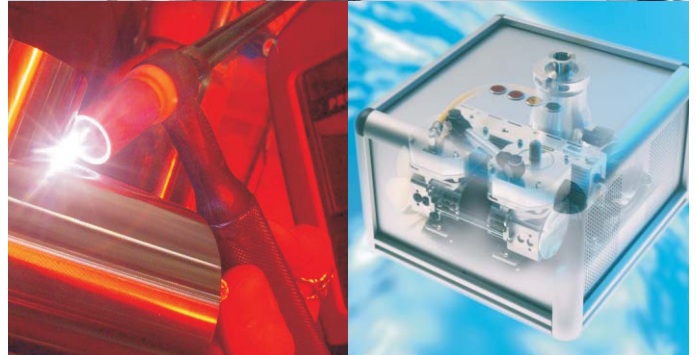
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# Rising to the uniformity challenge

Thomas Swan Scientific Equipment Ltd designs a range of reactors for the manufacture of semiconductor devices, such as light-emitting diodes, laser diodes and field-effect transistors. These reactors use a water-cooled “showerhead” developed by Creative Group, a UK-based vacuum technology company, to deliver gases to the reactor through an array of small tubes. The use of the showerhead ensures that the gases are uniformly distributed over the area of deposition.

The different gases are introduced to the reactor through different tubes, and they then react to form products that are deposited onto a substrate. By placing the showerhead, which contains approximately 100 injection tubes per square inch, close to the substrate, which is rotated at up to 600 revolutions per minute, it is possible to ensure that the thickness of the deposited layer is uniform across the entire area of the substrate.

The challenge for Creative Group was to develop a manufacturing process that could construct a showerhead gas-delivery system consisting of 9600 tubes, each with an internal diameter of 0.6 mm, within a working area with a diameter of 19 inches. Alternate rows of long and short tubes deliver gas from separate sources, with all tubes being water-cooled.

To make the showerhead, each tube is inserted into the predrilled lower plate and a “brazing” paste is applied to join each tube to the plate. The tubes are brazed to the plate in a vac-

uum furnace at a more than 1000 °C. A compound is applied to prevent the braze from migrating to areas where it is not wanted and to ensure that the tubes are not blocked.

Special vacuum furnace heat-cycle programmes were developed to ensure that the heat distribution across the assembly was even. This was difficult owing to the difference in thickness between the showerhead walls and the plates. To ensure a correct join and to minimize braze migration, the plate had to be heated evenly to within 5 °C of the optimum temperature.

The predrilled middle plate is then fitted over the tubes and brazed in the same manner, forming the water-cooled void. This void is tested with a mass spectrometer to ensure that water cannot leak through any of the 9600 tube joints. To complete the assembly, the upper plate is vacuum brazed in place over the long tubes. Throughout this process, including the three vacuum brazing operations, all of the tubes must remain open to ensure the even distribution of the reagent gases to the substrate. A flow test is undertaken on the final assembly to ensure that this has been achieved.

The density of tubes and the complexity of the vacuum brazing process have enabled this showerhead design to provide Thomas Swan with many technical benefits for its reactors.

*Paul Brooker is managing director of Creative Group ([www.creative-group.biz](http://www.creative-group.biz))*



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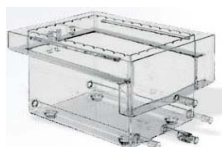
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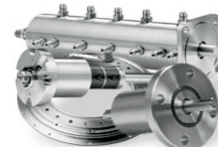
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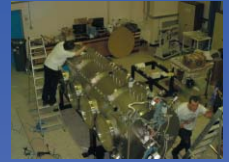
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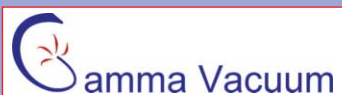


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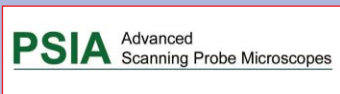


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# Mastering the vacuum

## An MSc in vacuum technology is a passport to a career in one of many different industries

Over the past 30 years, vacuum technology has revolutionized industrial and scientific processes, underpinning the advances made in many areas. There is a symbiotic relationship between the semiconductor and vacuum industries, with the development of new vacuum hardware leading to the creation of new generations of electronic devices. At the other end of the vacuum spectrum, “rough vacuum” is used in applications as varied as chilling lettuce, moving concrete and packaging meat. This proliferation of vacuum applications has led to a shortfall in suitably trained and qualified personnel.

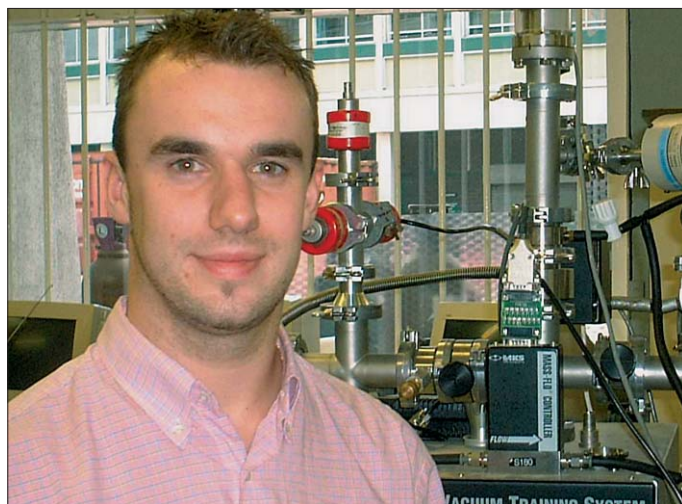
Historically, universities have found it difficult to position vacuum engineering in a specific subject area. Consequently it has been omitted from degree programmes. The MSc in vacuum engineering at Salford University was started five years ago with the support of the Engineering and Physical Sciences Research Council and many vacuum companies. Some of these – MKS Instruments, Varian Vacuum and Busch (UK) Ltd – play a significant role in ensuring that the latest developments are incorporated into the course. Full-time (12-month) and distance-learning (24–60 month) options are available.

Before learning about the MSc, I had little idea of how relevant vacuum technology was to so many different areas. However, I became interested in enrolling on the course when I realized the potential of such a qualification.

Last October, 14 people from a variety of backgrounds and countries began the course. While many of us had come directly from engineering or science degrees, there were also mature students, including two from the Libyan petrochemical industry. One advantage was that several grants were available to pay the fees and, in some cases, living costs too.

The course was modular and provided both a practical and a theoretical approach. The first semester familiarized students with basic vacuum concepts, and the second related these ideas to industrial applications and processes, including leak detection, thin-film processes and analytical technologies.

Each module was assessed by a combination of a lab report (worth 20% of the total mark), a written assignment (20%) and



**Philip Parsons found that Salford University's MSc in vacuum technology led to a healthy number of job offers.**

an examination (60%). The lectures were more informal than those that I had attended as an undergraduate and this made me feel more engaged with the subject. Indeed, one colleague said that the course had rekindled her interest in science and she has now applied to do a PhD in superconducting materials.

Mass spectrometry was the subject that interested me most, both from the point of view of the science and technology and also in terms of the resulting employment opportunities. The mass spectrometer is perhaps the most influential instrument in scientific use today, and a vast industry is involved in producing, maintaining and developing these devices, so I decided to do my project placement in this area.

The project takes place after the taught part of the course. The possibility of gaining experience in a relevant company appealed, although there was also the option of carrying out research at the university. I found that there was no shortage of industrial companies eager to take on a student. Five local firms offered me interviews. Finally I decided to work with GV Instruments in Manchester on a project relating to the nuclear industry. I have since been taken on full time as a test and installation engineer. An added bonus is that the position offers me the potential to travel the world for four months each year.

I thoroughly enjoyed the MSc course and it greatly improved my employment prospects. An array of industries relies on vacuum technologies and I have been offered jobs by companies in the UK, Spain and the US. I would recommend anyone with a scientific or engineering background to apply to join this course.

**Philip Parsons is a test and installation engineer at GV Instruments ([www.gvinstruments.co.uk](http://www.gvinstruments.co.uk)). Further information about vacuum courses at Salford is available from Richard Pilkington ([r.d.pilkington@salford.ac.uk](mailto:r.d.pilkington@salford.ac.uk); [www.cse.salford.ac.uk/vacuum](http://www.cse.salford.ac.uk/vacuum))**



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# The secret world of vacuum coating

**What do drill bits, food packing and architectural glass have in common? They all rely on vacuum coatings**

Vacuum coating is used widely in both consumer and industrial products. It has the unique ability to modify the characteristics of a surface through the addition of one or more thin-film layers. As the science of vacuum coating has developed, it has become possible to tailor the properties of the film by controlling morphology, composition, crystal orientation and stress.

Applications of vacuum coatings include the aluminium coating on compact discs, the titanium nitride (TiN) coating on drill bits and industrial cutting tools, the silicon dioxide (SiO<sub>2</sub>) coatings that act as a barrier to oxygen in food packaging, and low-emissivity (low-e) coatings on architectural and automotive glass. Low-e coatings make buildings more energy efficient, pleasant and attractive, while the gold-coloured TiN coatings on drill bits extend their life by three to four times.

Sputtering is a common vacuum coating technique. For example, aluminium can be sputtered from a target by argon ions then deposited on a workpiece (e.g. a CD). The argon ions strike the surface of the target, causing individual aluminium



The windows in these buildings were vacuum coated.

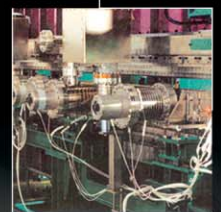
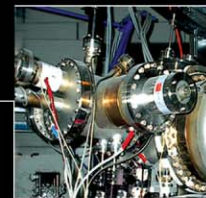
atoms to be “sandblasted” away. These then propagate to the workpiece, where they condense on the surface, just as steam condenses on a mirror. Few of the sputtered atoms are ionized (typically ~1%), so their transport is not significantly affected by electric or magnetic fields. Rather, the transport is dominated by gas kinetics and collisions.

The process can be modified by adding a reactive gas. In reactive sputtering, atoms from the target react with the gas molecules to form a product that is then deposited. For example, elemental silicon sputtered from the target can react with

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O<sub>2</sub> molecules to form SiO<sub>2</sub> at the surface of the workpiece. Reactive sputtering is a useful technique for depositing many compounds that are in common industrial use (e.g. TiN, TiO<sub>2</sub>, SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub>, SnO<sub>2</sub>, ZnO and Al<sub>2</sub>O<sub>3</sub>). Films of these compounds find applications in antireflective coatings, high-performance mirrors, solar control coatings, automotive glass, architectural glass, hard coatings on tools.

For semiconductor devices, characteristic dimensions have decreased and aspect ratios increased, making ionization of the target atoms increasingly important. There are many advantages to having highly ionized material. The main one is that ions can be directed to the workpiece by electrical or magnetic fields. An electrical bias on the workpiece's surface can cause the ions to go round corners and cover, or fill, high-aspect-ratio features, such as trenches in semiconductor devices.

An electrical bias on the surface of the workpiece also determines the energy of the ions that reach the surface. These can come from the target material or the process gas, and both will deliver energy to the surface of the workpiece, controlled by the bias voltage. A properly chosen voltage permits denser, higher-quality films and makes it possible to tune the properties of the film (e.g. index of refraction, optical loss, conductivity and density) to match the application.

In conventional magnetron sputtering, only a tiny fraction of the sputtered target atoms are ionized. Larger ionization fractions have been created by multiple means with plasmas and cathodic arc systems. The latter is used widely for rugged applications, such as applying coatings to cutting and forming

tools with compounds, and providing lifetime functional coatings on door hardware and plumbing fixtures. In more precise applications, such as semiconductor manufacturing, highly evolved sputtering magnetrons can ionize greater fractions of the target atoms with high repeatability.

In general, new technologies can be evolutionary or disruptive, with the latter fundamentally changing consumer expectations. Disruptive technologies, such as large-screen plasma and LCD flat-panel displays, can drive demand for industrial vacuum coating equipment, often fuelled by consumer demand, with demand accelerating when the price drops significantly.

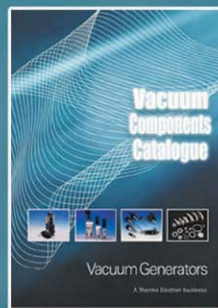
It is hard to predict future trends because so many technologies are competing for wide-scale adoption. In any case, emerging applications always place greater demands on thin-film and coating technology. Process power supplies are expected to have lower arc energy and better arc-management characteristics. Mass flow controllers are increasingly expected to have digital interfaces and to be insensitive to the gas supply pressure, with the user able to select the calibrations for multiple gases. Moreover, atomic layer deposition, a chemical-based technique for depositing one monolayer at a time, may supplant sputtering in some semiconductor manufacturing process steps. But, even if it does, vacuum coating will be with us for some time to come.

*David J Christie is a senior scientist at Advanced Energy Industries, Inc ([www.advanced-energy.com](http://www.advanced-energy.com)), is on the adjunct faculty in electrical and computer engineering at Colorado State University and is on the board of directors of the Society of Vacuum Coaters ([www.svc.org](http://www.svc.org)).*

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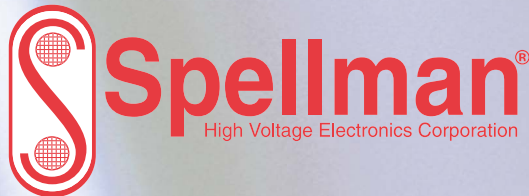
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# Innovative approaches to pumping

The large sheets of architectural glass that are used in commercial and residential buildings are coated for various reasons: to alter their colour or reflective properties from an aesthetic consideration, and to control the temperature in the building, which can lead to significant improvements in energy efficiency. Indeed, the proper use of coatings to block sunlight or reflect thermal radiation back into a building can lead to financial savings, especially in large commercial buildings.

Modern architectural glass can contain up to 12 different layers, and more in some applications. While the complexity of layers is increasing, it is also essential to maintain the reliability of the production processes that are used to make the glass. In addition, higher throughput values and lower running costs are high priorities among glass manufacturers.

Most systems that produce high-volume architectural glass use physical vapour deposition technology to form the films and coatings. A target material is either evaporated or sputtered (physically ejected by high-energy ions), and the molecules from the target are directed to the glass surface, where they form a thin layer of uniform thickness.

Vacuum is required in the process chambers for two reasons: the formation of the plasma requires reduced pressure, and the sputtered atoms need unhindered routes to the substrate.

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*Willijan Vissers is the manager for industrial vacuum processes at Varian Incorporated ([www.varianinc.com](http://www.varianinc.com))*



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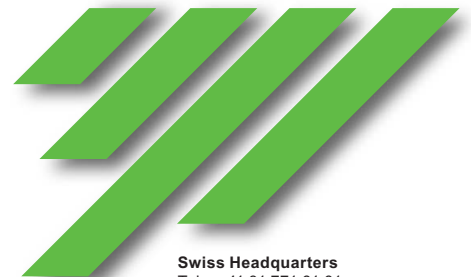
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# Model shows how to turn one pump into two

The late 1990s saw the introduction of split-flow turbo pumps in which a second inlet enabled two different vacuum regimes to be pumped by the same turbo pump. This technology can be applied to more conventional pumps, but requires an understanding of the pay-off between pumping speed and compression ratio between the two inlets.

Any molecular-flow gas-transfer pump – in which gases are removed from the system rather than trapped by the pump – can be thought of in terms of conductance. The pumping speed is described by the conductance in the direction of pumping, while the compression of the pump is related to the conductance in the opposite direction (the contraflow).

A pump can therefore be represented as a Zener diode, with a critical exhaust pressure at which contraflow becomes significant. Our model, the modified conductance model, was based on the idea that the rotation of the pump dynamically modified

the geometry of the pump in the reference frame of a gas molecule, increasing the conductance for gas molecules travelling down the pump and decreasing it for those travelling up the pump. The idea is best understood by visualizing the different stages in the pump (that is, the different sets of blades that do the pumping) as a series of Venetian blinds.

As a molecule passes through a stage, the motion of the blade makes the angle of the blade more parallel to the direction of motion of the molecules travelling in the pumping direction, but also more perpendicular to those in contraflow. It is as if the blind is opened to molecules travelling down the pump and closed to those travelling up it. The effect is compounded at each stage of the pump, leading to the high pumping speeds and compression ratios that make the turbo pump such an attractive technology.

This model proved to be remarkably accurate, predicting pumping speeds that were within 10% of those published by the pump manufacturer. At higher pressures we had to assume that viscous flow conductances were unaffected by the motion of the blades to produce the characteristic fall-off in pumping speed and compression ratio that is seen above  $10^{-3}$  mbar. When all of this was done we plotted the pumping speed and compression ratio as a function of distance along the pump. With this information to hand we could then decide on the best place to add a second inlet and convert an ordinary turbo pump into a split-flow version.

*Andy Pearce is managing director of Oxford Vacuum Science Limited ([www.oxford-vacuum.com](http://www.oxford-vacuum.com))*

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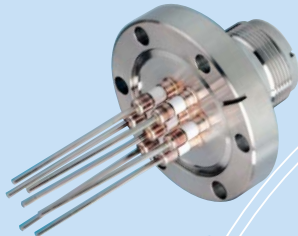
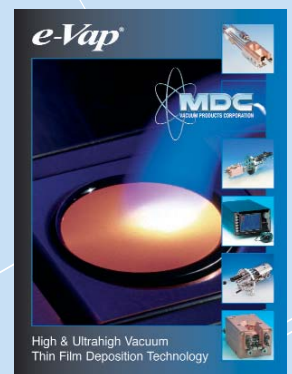
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